JOURNAL OF RESEARCH of the National Bureau of Standards—A. Physics and Chemistry
Vol. 74A, No. 4, July–August 1970

Specific Heats of Fluorine at Coexistence*

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(February 28, 1970)

Experimental specific heats of fluorine at constant total volume are reported for the two-phase, liquid-vapor system from triple- to the critical point. Specific heats of liquid along the coexistence path are derived by use of PVT data for the two-phase system, and are represented by a formula to facilitate computations of thermodynamic properties.

Key words: Fluorine; liquid-vapor coexistence; saturated liquid; saturation; specific heats; thermodynamic properties; two-phase.

List of Symbols

A_i	coefficients for various formulas
C_o	gross heat capacity, adjusted for capillary tube
$C_b(T)$	tare heat capacity of empty bomb
$\underline{C}_v^0(T)$	specific heat at $\rho=0$
$\bar{C}_v(\rho, T)$	specific heat of two-phase sample
$C_\sigma(T)$	specific heat of liquid on coexistence path
G	Gibbs free energy per mole
J	the joule
k	conversion factor, 101.325 J/liter atm
ℓ	the liter
N	total g moles of fluid in closed system
N_b	g moles of fluid in the bomb
N_c	g moles of fluid in the capillary tube
P	pressure, 1 MN/m^2=9.86923 atm
Q	calorimetric heat input, J
ρ	density (subscripts g and l refer to vapor and liquid)
$\rho_{av}\equiv$	N_b/V_b, overall density
T	temperature, K, on the IPTS (1968)
T_a	average temperature in ΔT
ΔT	calorimetric temperature increment, K
$v\equiv$	$1/\rho$, molal volume
V_b	volume of the calorimeter bomb

1. Introduction

These specific heat measurements are part of a program to determine thermodynamic properties of compressed gaseous and liquid fluorine [1, 2].[1] For computations of the thermodynamic properties of the compressed liquid it may be convenient to use the saturated liquid path from the triple point to near the critical point. Data for specific heats of liquid on this path are derived from experimental observations on the two-phase, liquid-vapor system at constant volume by use of the PVT properties at coexistence.

2. Experimental Procedure

The commercial fluorine very generously was purified for us by G. K. Johnson at the Argonne National Laboratory by fractional distillation. Analyses of samples from our laboratory show a purity of at least 99.99 percent (determined by residual gas analysis after reaction of the fluorine with mercury). Most of the apparatus and procedures are identical with those described for our work on oxygen [3].

The fluorine sample-handling system is shown schematically by figure 1. The small circles represent valves. Numbers 8, 9, and 11 are packless valves, kindly given to us by G. C. Straty [4]. The pure fluorine is stored at 15 atm (1.5 MN/m^2) pressure in the 10-liter, stainless steel tank. It is introduced to the calorimeter by condensing it first in the trap, cooled with liquid nitrogen. Pressures to 200 atm (20 MN/m^2) are obtained in the calorimeter as the trap warms toward room temperature. The null-pressure diaphragm, NPD, isolates the fluorine from the remainder of the precision, dead-weight gage system. At the end of an experiment, fluorine is returned to the 10-liter storage vessel. Sodium fluoride pellets are activated by heating sodium bifluoride. They absorb traces of HF which could arise from organic contaminants in the all-metal system. The activated alumina converts fluorine into oxygen for protection of the rotary pump (containing fluorocarbon oils).

*This work was carried out at the National Bureau of Standards under sponsorship of the U.S. Air Force (MIPR No. FO4611–70–x–0001).

[1] Figures in brackets indicate the literature references at the end of this paper.

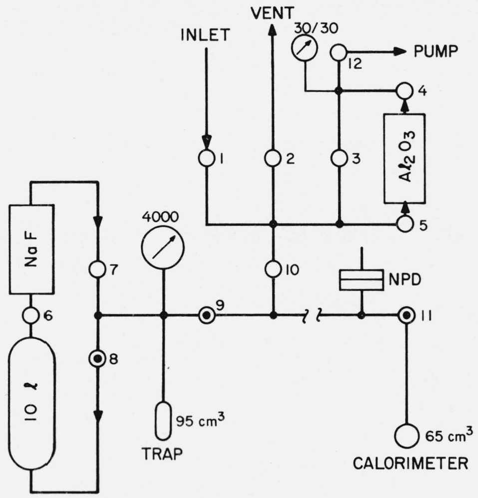

FIGURE 1. *Fluorine sample-handling system.*

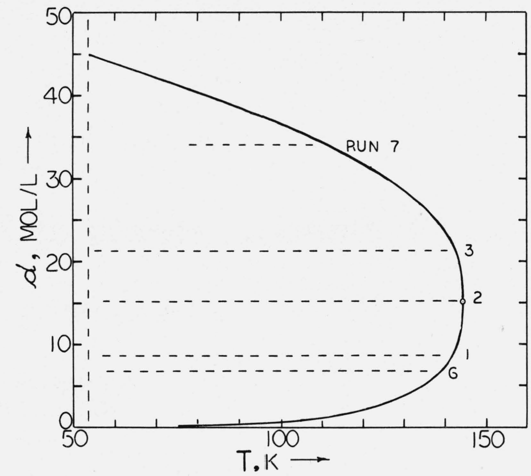

FIGURE 2. *Locus of two-phase specific heat measurements.*

TABLE 1. *Loading conditions for the samples*

Run	T, K	P, Atm	P, MN/m²	V, cm³	D, Mol/ℓ	N, Mol
1.......	174.825	83.142	8.4244	73.014	8.709	0.6360
2.......	166.789	102.908	10.4272	73.008	15.184	1.1087
3.......	175.609	183.593	18.6026	73.114	21.245	1.5535
6.......	195.075	85.469	8.6601	73.079	6.770	0.4948
7.......	116.282	87.461	8.8620	72.850	34.098	2.4843

Temperatures are on the IPTS (1968) via a new calibration table for our platinum resistance thermometer provided by the NBS temperature section [5]. To avoid entering a calibration table in the computer memory for every set of calculations, we have used a formula for computing temperature directly as a function of the observed thermometer resistance, as described in the appendix.

Tare heat capacity of the empty calorimeter bomb was measured in 29 intervals from 58 to 297 K. Data and the formulation are given in the appendix.

The amount of sample for each isochore of specific heat measurements is given in table 1. As in [3], we used an equation of state to find the density corresponding to the observed filling temperature and pressure. For present work the equation is similar to that used in [6], adjusted for forthcoming PVT data on fluorine.

3. Calculations and Results

Calculations in the present work differ from [3] only in modification of the heat of vaporization used for the capillary tube adjustment, as pointed out by R. E. Barieau in section 7 of [3]. With symbols listed above, the gross heat capacity, adjusted for heat effect of vapor forced into the capillary tube, is—

$$C_0 = [Q - T_a \cdot (dP/dT) \cdot \delta N_c/\rho_g]/\Delta T. \quad (1)$$

Specific heat of the two-phase sample, adjusted for heat effect of the bomb expansion, is—

$$\bar{C}_v = [C_0 - C_b - T_a \cdot (dP/dT) \cdot (dV_b/dT)]/N_b. \quad (2)$$

Physical properties needed for these calculations are given in the appendix.

Figure 2 locates the experimental runs by dashed lines inside the coexistence envelope. They represent the overall density of the two-phase system at constant volume. Table 2 gives the experimental conditions and both the direct and derived results for these two-phase specific heat measurements. The pressure and the densities of vapor and of liquid are computed by formulas in the appendix. The first column of table 2 gives the experimental run (sequence) followed by two digits for the individual measurement at this density. Next is the average temperature in the interval and the bomb volume derived from the pressure at this average temperature. The fourth column gives overall density, ρ_{av}. Following columns give the calorimetric temperature increment, ΔT; the experimental gross heat capacity prior to any adjustments, $Q/\Delta T$; the tare heat capacity; the specific heat, $\bar{C}_v$, of the two-phase sample; the derived specific heat, C_σ, of liquid along the coexistence path; and finally the estimated uncertainties (errors) in these specific heats, calculated as described in [3].

Figure 3 shows the two-phase specific heat data for our first three runs, plotted in coordinates $\bar{C}_v/T$ versus T. This plot has been used for interpolation of $\bar{C}_v/T$ onto isotherms, useful to derive values for d^2P/dT^2 via the thermodynamic relation,

$$\bar{C}_v/T = -d^2G/dT^2 + [d^2P/dT^2]/\rho. \quad (3)$$

Results in table 3 are compared with values from the vapor pressure equation of the appendix.

Specific heat of liquid along the coexistence path is derived by the relation [7]

$$C_\sigma = \bar{C}_v - \frac{T_a}{\rho} \cdot \left\{ \frac{1}{\rho} \frac{d\rho}{dT} \frac{dP}{dT} + \left[\frac{\rho \cdot V_b}{N_b} - 1 \right] \cdot \frac{d^2P}{dT^2} \right\}. \quad (4)$$

TABLE 2. *Specific heats of fluorine at coexistence*

ID	Temp. deg. K	V, bmb cm^3	D, avr mol/l	ΔT deg. K	$Q/\Delta T$ J/deg.	Tare J/deg.	$\bar{C}_v$ J/M-K	C_σ J/M-K	Errors, percent	
									$\bar{C}_v$	C_σ
101	56.998	72.669	8.752	2.682	58.930	24.237	54.550	54.309	0.48	0.48
102	60.751	72.673	8.751	4.825	62.028	26.340	56.116	55.618	.41	.42
103	66.124	72.679	8.751	5.923	66.399	29.866	57.444	56.279	.41	.43
104	72.184	72.688	8.749	6.208	71.556	33.916	59.183	56.700	.42	.45
105	78.516	72.698	8.748	6.472	77.238	37.960	61.758	57.140	.42	.49
106	85.115	72.710	8.747	6.725	83.556	41.886	65.519	57.820	.43	.54
107	91.892	72.724	8.745	6.849	90.363	45.593	70.388	58.689	.43	.60
108	98.944	72.740	8.743	6.932	97.859	49.108	76.643	60.040	.42	.66
109	105.907	72.757	8.741	7.029	105.644	52.253	83.930	61.940	.42	.73
110	112.955	72.777	8.739	7.093	113.841	55.131	92.244	64.475	.41	.80
111	120.087	72.799	8.736	7.215	122.778	57.759	102.096	68.441	.40	.86
112	126.982	72.823	8.733	6.677	132.505	60.054	113.716	74.905	.40	.91
113	133.380	72.847	8.730	6.167	143.436	61.992	127.764	86.239	.40	.94
114	137.922	72.866	8.728	2.974	152.921	63.267	140.725	102.443	.46	1.04
201	57.538	72.669	15.257	4.551	85.452	24.502	54.975	54.850	.37	.37
202	62.557	72.675	15.255	5.496	89.647	27.492	56.062	55.749	.36	.36
203	68.562	72.683	15.254	6.522	94.650	31.506	56.953	56.211	.36	.37
204	75.531	72.693	15.252	7.428	100.628	36.086	58.214	56.622	.36	.38
205	84.071	72.708	15.248	9.668	108.467	41.285	60.595	57.409	.35	.40
206	93.327	72.727	15.244	8.854	117.344	46.337	64.043	58.563	.36	.45
207	101.874	72.747	15.240	8.260	126.022	50.470	68.137	60.259	.37	.49
208	109.854	72.768	15.236	7.724	134.658	53.901	72.824	62.765	.37	.53
209	117.335	72.790	15.231	7.253	143.307	56.777	78.021	66.354	.37	.57
210	125.182	72.816	15.226	5.493	153.127	59.476	84.391	72.317	.39	.62
211	130.632	72.836	15.221	5.438	161.284	61.181	90.114	79.755	.39	.63
212	135.869	72.857	15.217	5.076	171.190	62.700	97.572	93.541	.39	.64
213	140.687	72.878	15.212	4.653	186.562	64.005	109.849	130.404	.38	.62
214	143.436	72.890	15.210	0.904	204.756	64.712	125.623	256.445	.70	.75
301	55.173	72.667	21.378	2.729	107.984	23.496	54.386	54.343	.39	.40
302	57.860	72.670	21.377	2.654	110.311	24.667	55.130	55.055	.40	.40
303	61.376	72.674	21.376	4.386	113.341	26.733	55.751	55.608	.36	.36
304	66.187	72.679	21.375	5.244	117.404	29.908	56.322	56.025	.35	.35
305	71.829	72.687	21.372	6.047	122.139	33.683	56.940	56.350	.35	.36
306	78.281	72.698	21.369	6.865	127.752	37.815	57.893	56.809	.34	.36
307	84.987	72.710	21.366	6.562	133.702	41.813	59.149	57.394	.35	.38
308	91.937	72.724	21.361	7.356	140.093	45.617	60.813	58.257	.35	.40
309	99.435	72.741	21.356	7.659	147.276	49.341	63.037	59.622	.35	.42
310	107.126	72.761	21.351	7.741	154.930	52.772	65.734	61.643	.35	.44
311	114.649	72.782	21.344	7.325	162.713	55.780	68.799	64.563	.35	.46
312	121.502	72.804	21.338	6.996	170.708	58.249	72.339	68.925	.36	.48
313	128.311	72.827	21.331	6.653	179.334	60.471	76.422	75.868	.36	.49
314	133.951	72.849	21.324	4.659	188.464	62.157	81.180	87.061	.38	.52
315	138.484	72.868	21.319	4.443	198.904	63.419	86.861	107.109	.38	.52
601	57.905	72.670	6.810	7.348	51.665	24.691	54.510	54.116	.41	.41
602	64.890	72.678	6.809	6.635	57.346	29.037	57.209	55.883	.43	.45
603	72.088	72.688	6.808	7.771	63.442	33.854	59.791	56.442	.43	.48
604	79.891	72.701	6.807	7.852	70.512	38.803	64.075	56.976	.44	.55
605	87.709	72.715	6.805	7.802	78.174	43.344	70.382	57.829	.45	.63
606	95.511	72.732	6.804	7.834	86.323	47.440	78.536	59.015	.44	.73
607	103.310	72.751	6.802	7.838	94.932	51.117	88.481	60.760	.44	.83
608	111.099	72.772	6.800	7.774	104.070	54.402	100.274	63.435	.43	.93
609	118.847	72.795	6.798	7.752	113.803	57.321	113.982	67.447	.42	1.02
610	126.540	72.821	6.795	7.669	124.691	59.913	130.613	74.274	.41	1.10
611	133.839	72.849	6.792	6.960	137.309	62.124	151.266	86.946	.40	1.14
701	77.842	72.697	34.173	2.136	179.095	37.542	56.979	56.793	.42	.43
702	80.589	72.702	34.170	3.358	181.333	39.227	57.202	56.992	.37	.38
703	84.641	72.709	34.167	4.745	184.786	41.614	57.631	57.402	.35	.36
704	89.737	72.719	34.162	5.447	189.068	44.450	58.212	58.005	.34	.36
705	95.545	72.732	34.156	6.172	193.931	47.457	58.959	58.882	.34	.36
706	101.200	72.745	34.150	5.147	198.700	50.162	59.788	60.008	.35	.38
707	106.285	72.758	34.144	5.033	203.295	52.415	60.729	61.434	.35	.38

TABLE 3. *Comparisons* d^2P/dT^2 *for fluorine*

$\bar{C}_v/T = -d^2G/dT^2 + (d^2P/dT^2)\cdot v$		
T, K	d^2P/dT^2, atm/K^2	
	Expt'l. $\bar{C}_v/T$	V.P. eq. (5.3)
80	0.0080 ± 0.0008	0.0073
90	.0140 .0008	.0133
100	.0212 .0008	.0203
110	.0289 .0008	.0280
120	.0371 .0008	.0363
130	.0475 .0009	.0464
140	.063 .0035	.0647

Figure 4 shows C_σ for the liquid on this path. On the scale of this plot the data appear to be linear in temperatures below the boiling point (85 K). Figure 5 examines behavior of the data as $T \rightarrow T_c$. Upon subtracting C_v^0, we obtain a nearly linear plot in the logarithmic coordinates of figure 5, corresponding to

$$C_\sigma \sim C_v^0 + \text{const} \cdot (1 - T/T_c)^{-\epsilon} \tag{5}$$

where the exponent is roughly $\epsilon = 0.5$.

4. Analytical Representation of C_σ

For thermal computations along the coexistence path we need a description of $C_\sigma(T)$. It is convenient

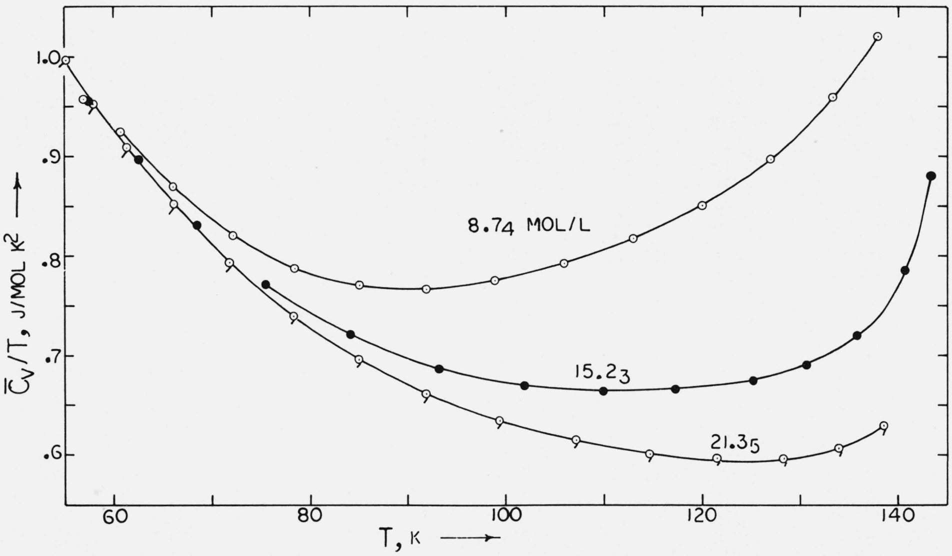

FIGURE 3. *Two-phase specific heats of fluorine at constant volume.*

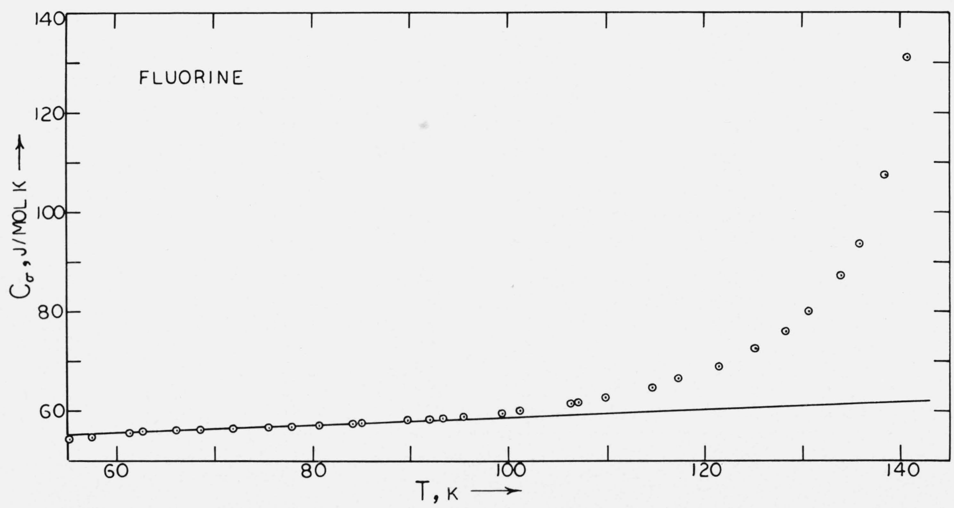

FIGURE 4. *Derived specific heats of liquid fluorine along the coexistence path.*

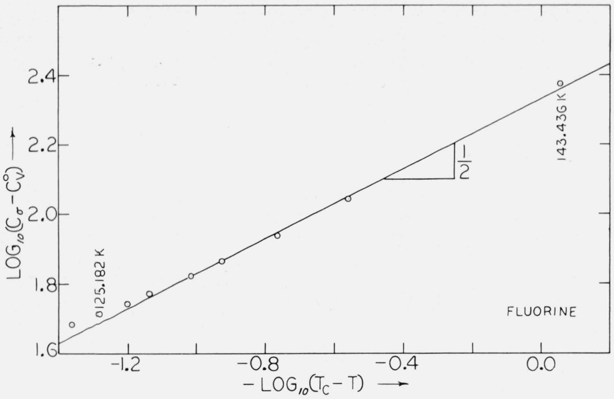

FIGURE 5. *Residual specific heat:* $(C_\sigma - C_v^0)$, *J/mol K, versus* $(T_c - T)$ *in log-log coordinates.*

to define a reduced independent variable which is zero at the critical point, $x \equiv (1 - T/T_c)$. We have sought a simpler form than was used for oxygen. The following expression,

$$C_\sigma = A_1/x^\epsilon + \sum_{i=2}^{N} A_i \cdot x^{i-2}, \tag{6}$$

is sufficient for oxygen with $N=3$ terms only, giving an rms relative deviation of 0.33 percent for the 86 data in [3]. For the present fluorine data, however, we must take $N=6$ terms for optimum representation, $\epsilon = 0.593$,

$A_1 = 10.76\,214$ $\quad$ $A_4 = -148.92\,825$

$A_2 = 33.88\,593$ $\quad$ $A_5 = 341.88\,386$

$A_3 = 34.85\,555$ $\quad$ $A_6 = -265.99\,546$

Table 4 compares the data used for C_σ with values calculated from (6). There is a systematic difference of roughly 0.1 percent between different runs. This increases as the amount of sample (density) decreases. For this reason, runs at densities below critical were omitted in deriving constants for the fitting function. The rms relative deviation of 0.11 percent for (6) with the remaining data is smaller than the uncertainty of individual points. Figure 6 shows low-temperature behavior of the C_σ data relative to the calculated line.

A few specific heats have been reported previously for fluorine in the condensed phase at $T < 85$K, [8,9]. No clear description of the experimental conditions was given. The data in [9] are labeled C_p, and previous reports mention recording the pressure before and after each heating period [10]. The reported values in table 5 are compared with our calculated values from (6) for liquid on the coexistence path.

TABLE 4. *Derived and calculated values of* C_σ, *J/mol K*

ID	T, K	Csat	Calc	Percent
	53.481		54.489	
	54.000		54.578	
301	55.173	54.343	54.766	
	56.000		54.890	
201	57.538	54.850	55.104	
302	57.860	55.055	55.147	−0.17
303	61.376	55.608	55.554	.10
202	62.557	55.749	55.672	.14
304	66.187	56.025	55.991	.06
203	68.562	56.211	56.172	.07
305	71.829	56.350	56.403	−.09
204	75.531	56.622	56.658	−.06
701	77.842	56.793	56.824	−.05
306	78.281	56.809	56.857	−.08
702	80.589	56.992	57.037	−.08
205	84.071	57.409	57.344	.11
703	84.641	57.402	57.399	.01
307	84.987	57.394	57.433	−.07
704	89.737	58.005	57.976	.05
308	91.937	58.257	58.279	−.04
206	93.327	58.563	58.490	.13
705	95.545	58.882	58.861	.04
309	99.435	59.622	59.631	−.01
706	101.200	60.008	60.036	−.05
207	101.874	60.259	60.201	.10
707	106.285	61.434	61.437	−.00
310	107.126	61.643	61.707	−.10
208	109.854	62.765	62.670	.15
311	114.649	64.563	64.754	−.29
209	117.335	66.354	66.200	.23
312	121.502	68.925	68.996	−.10
210	121.182	72.317	72.276	.06
313	128.311	75.868	76.004	−.18
211	130.632	79.755	79.642	.14
314	133.951	87.061	87.059	.00
212	135.869	93.541	93.425	.12
315	138.484	107.109	107.265	−.15
213	140.687	130.404	130.355	.04
214	143.436	256.445	256.446	−.00

NP = 34, RMSPCT = 0.112

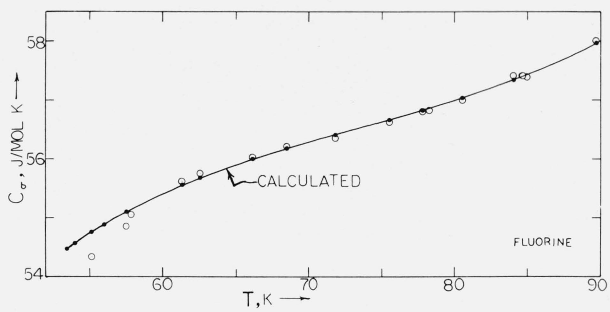

FIGURE 6. *Behavior of* C_σ *data at low temperatures.*

5. Appendixes

5.1. Resistance Thermometer Formula

Coefficients for eq 5.1 were obtained by least squares. Data are from NBS calibration tables on the

TABLE 5. *Other specific heats for the condensed phase, J/mol K*

T, K	C_x, unknown conditions		C_σ
	Kanda [8]	Hu et al. [9]	Eq (6)
57.50	45.4		55.1
58.14		57.3	55.2
62.27		57.3	55.6
62.51	45.7		55.7
67.05		56.7	56.1
67.49	45.9		56.1
71.86		56.8	56.4
76.60		57.4	56.7
77.10	46.5		56.8
81.32		57.7	57.1
83.41	46.9		57.3

IPTS (1968) for platinum thermometer L.N.1,506,157. Maximum deviations are 4 parts per million (0.14 mK) in the range $20 \leqslant T \leqslant 100$ K, and 6 parts per million (1.95 mK) in the range $100 \leqslant T \leqslant 600$ K. Variables for (5.1) include $x \equiv R/R_1$ where R is thermometer resistance and R_1 is a constant to be found; $T_0 \equiv 273.15$ K; $u \equiv \log_e(1+x)$; and $w \equiv \log_e(1+1/x)$,

$$T/T_0 = A_1 + A_2 \cdot x + A_3 \cdot u + A_4 \cdot x \cdot u + x \cdot \sum_{i=5}^{17} A_i \cdot w^{i-3}. \qquad (5.1)$$

Table 5.1–A gives the constants for (5.1). The number of figures in each is based on the maximum value of each term in (5.1). Table 5.1–B gives a selection of data and calculated values for T and for the first derivative, dT/dR.

TABLE 5.1–A. *Constants for resistance thermometer*

$R_1 = 13.0$ ohm
$A_1 = -1.0874\ 7037\ .\ .\ . \times 10^1$
$A_2 = -2.6699\ 4012\ .\ .\ . \times 10^0$
$A_3 = 9.2443\ 2475\ .\ .\ . \times 10^0$
$A_4 = 7.9896\ 2549\ .\ .\ . \times 10^{-1}$

$A_5 = 2.0807\ 0866\ .\ .\ . \times 10^1$
$A_6 = -1.8099\ 5755\ .\ .\ . \times 10^1$
$A_7 = 2.2519\ 8377\ 2\ .\ . \times 10^1$
$A_8 = -1.9086\ 9836\ 9\ 4\ . \times 10^1$
$A_9 = 1.2724\ 9642\ 9\ 9\ . \times 10^1$

$A_{10} = -6.3571\ 7850\ 4\ 7\ 0 \times 10^0$
$A_{11} = 2.3872\ 5690\ 3\ 4\ 4 \times 10^0$
$A_{12} = -6.6558\ 6282\ 7\ 2\ 7 \times 10^{-1}$
$A_{13} = 1.3550\ 6466\ 3\ 3\ 4 \times 10^{-1}$
$A_{14} = -1.9527\ 0069\ 5\ 7\ 9 \times 10^{-2}$

$A_{15} = 1.8847\ 0886\ 4\ 3\ . \times 10^{-3}$
$A_{16} = -1.0919\ 0062\ 3\ 0\ . \times 10^{-4}$
$A_{17} = 2.8697\ 1011\ 5\ .\ . \times 10^{-6}$

5.2. Tare Heat Capacity C_b of the Empty Calorimeter

These heat capacities were measured by procedures identical with those used when the calorimeter contained fluid. Results are given here to show the precision attainable in absence of contained fluid. We express C_b in J/K, and describe the data by use of argument $x \equiv 100/T$,

$$\log_e(C_b/50) = \sum_{i=0}^{7} C_i \cdot x^i, \qquad (5.2)$$

$C_0 = 0.834\ 3170$ $\quad C_4 = -0.617\ 8472$
$C_1 = -1.254\ 9634$ $\quad C_5 = 1.434\ 6722$
$C_2 = 1.404\ 5656$ $\quad C_6 = -0.792\ 6938$
$C_3 = -1.167\ 3943$ $\quad C_7 = 0.151\ 4253.$

Experimental and calculated values for C_b are compared in table 5.2.

TABLE 5.1–B. *Resistance thermometer comparisons*

R, ohm	Temperature, K		DT/DR, K/ohm	
	Data	Calcd	Data	Calcd
0.10822	20	20.00000	54.450	53.996
.15046	22	22.00001	42.220	41.960
.20387	24	24.00010	33.910	33.744
.26917	26	25.99998	28.140	28.013
.43669	30	29.99999	20.870	20.802
.71483	35	34.99999	15.920	15.886
1.06277	40	39.99994	13.210	13.188
1.92143	50	50.00002	10.610	10.600
2.92121	60	60.00002	9.580	9.576
3.99152	70	69.99999	9.180	9.177
5.09086	80	80.00004	9.040	9.045
6.19807	90	89.99990	9.030	9.032
7.30315	100	100.00003	9.069	9.072
9.49254	120	120.00031	9.199	9.202
11.65079	140	139.99974	9.326	9.328
13.78232	160	159.99946	9.431	9.434
15.89232	180	180.00029	9.519	9.522
17.98437	200	200.00103	9.596	9.597
20.57753	225	225.00024	9.681	9.682
23.14885	250	249.99855	9.760	9.761
25.49666	273	272.99897	9.830	9.832
28.23168	300	300.00079	9.911	9.914
30.74399	325	325.00188	9.988	9.989
33.23712	350	350.00185	10.065	10.066
35.51399	373	373.00105	10.136	10.137
38.16643	400	399.99978	10.220	10.221
43.02058	450	449.99831	10.379	10.380
47.80024	500	499.99964	10.541	10.543
52.50580	550	550.00194	10.708	10.710
57.13738	600	599.99805	10.881	10.880

5.3. The Vapor Pressure of Fluorine

The equation from [11] uses argument $x \equiv (1-T_t/T)/(1-T_t/T_c)$,

$$\log_e(P/P_t) = A_1 \cdot x + A_2 \cdot x^2 + A_3 \cdot x^3 + A_4 \cdot x \cdot (1-x)^\epsilon. \qquad (5.3)$$

Constants are reported in [2],

$P_t = 252.0$ N/m^2 $\quad A_1 = 7.8959\ 2346$
$T_t = 53.4811$ K $\quad A_2 = 3.3876\ 5063$
$T_c = 144.31$ K $\quad A_3 = -1.3459\ 0196$
$\epsilon = 1.4327$ $\quad A_4 = 2.7313\ 8936.$

TABLE 5.2. *Experimental and calculated C_b, J/K*

T_{av}, K	ΔT	C_b, J/K	Calc	Percent
58.263	5.540	24.881	24.882	−0.003
63.565	5.132	28.160	28.154	.021
68.400	4.569	31.382	31.397	−.050
73.178	5.016	34.579	34.567	.035
78.403	5.458	37.895	37.891	.011
84.151	6.067	41.330	41.332	−.003
89.961	5.590	44.566	44.570	−.008
95.780	6.119	47.565	47.573	−.017
102.108	6.573	50.582	50.576	.012
108,805	6.860	53.463	53.473	−.018
115.658	6.896	56.174	56.159	.025
122.840	7.515	58.689	58.703	−.024
130.592	8.055	61.212	61.169	.070
130.114	8.062	61.016	61.024	−.014
138.297	8.378	63.352	63.368	−.026
146.798	8.738	65.541	65.543	−.004
155.637	9.048	67.559	67.564	−.007
164.902	9.637	69.436	69.459	−.033
174.769	10.274	71.283	71.266	.024
185.191	11.128	72.984	72.976	.011
196.516	11.765	74.625	74.643	−.024
208.533	12.559	76.271	76.229	.054
221.291	13.273	77.739	77.745	−.007
234.509	13.536	79.123	79.162	−.050
247.911	13.702	80.442	80.467	−.031
254.509	13.782	81.091	81.068	.029
268.123	13.965	82.256	82.230	.033
282.114	14.621	83.338	83.329	.011
296.823	15.517	84.378	84.395	−.020

NP = 29, RMSPCT = 0.028

5.4. The Vapor Density ρ_g of Fluorine

The equation for saturated vapor [12] uses arguments $x \equiv T/T_c$ and $z \equiv (1-x)$,

$$\log_e(\rho_g/\rho_c) = A_1 \cdot (1-1/x) + A_2 \cdot z^{0.35} + \sum_{i=3}^{7} A_i \cdot z^{i-2}. \tag{5.4}$$

Constants are reported in [2],

$\rho_c = 15.10$ mol/liter
$T_c = 144.31$ K
$A_1 = 4.8554\,7085$
$A_2 = -1.9601\,5519$
$A_3 = -0.1880\,6690$
$A_4 = 6.2116\,5939$
$A_5 = -22.9600\,8970$
$A_6 = 46.9524\,6230$
$A_7 = -43.0650\,2700$

5.5. The Liquid Density ρ_l of Fluorine

The saturated liquid densities are described in [2] with the same arguments as in section 5.4 above,

$$\rho_l/\rho_c = 1 + A_0 \cdot z^{0.35} + \sum_{i=1}^{5} A_i \cdot z^i, \tag{5.5}$$

$A_0 = 1.8188\,1076$
$A_1 = 0.8752\,3649$
$A_2 = -0.8504\,5891$
$A_3 = 1.3728\,4761$
$A_4 = -1.0133\,1503$
$A_5 = 0.2738\,4013.$

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(Paper 74A4–616)